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**Su et al.**

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(54) **VERTICAL POWER MOSFET AND METHODS FOR FORMING THE SAME**

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(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(65) **Prior Publication Data**

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(57) **ABSTRACT**

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**H01L 29/66** (2006.01)

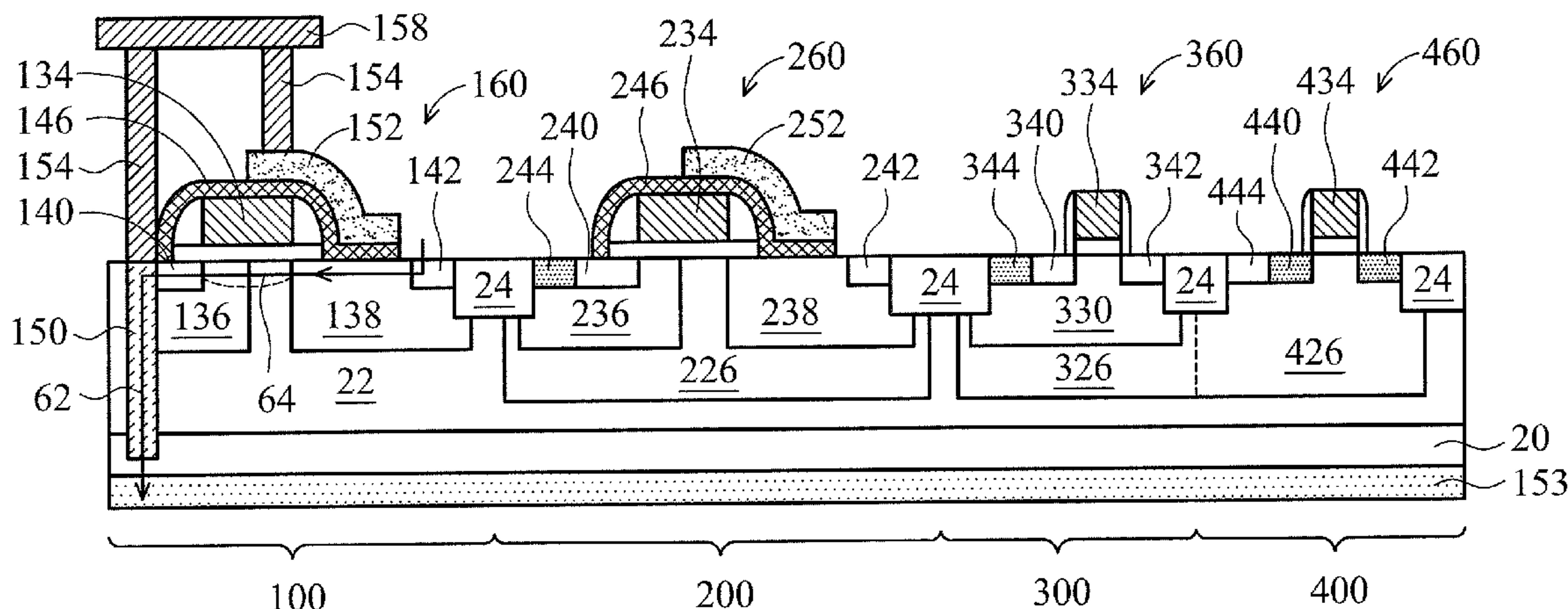
(52) **U.S. Cl.**  
USPC ..... **257/340**; 257/339; 257/338; 257/336;  
257/337; 257/335; 257/341; 257/342; 257/343;  
257/E29.255; 257/E29.256; 257/E29.257;  
257/E29.258; 257/E29.259; 257/E29.26;  
257/E29.261; 257/E29.262

A device includes a semiconductor region in a semiconductor chip, a gate dielectric layer over the semiconductor region, and a gate electrode over the gate dielectric. A drain region is disposed at a top surface of the semiconductor region and adjacent to the gate electrode. A gate spacer is on a sidewall of the gate electrode. A dielectric layer is disposed over the gate electrode and the gate spacer. A conductive field plate is over the dielectric layer, wherein the conductive field plate has a portion on a drain side of the gate electrode. A deep metal via is disposed in the semiconductor region. A source electrode is underlying the semiconductor region, wherein the source electrode is electrically shorted to the conductive field plate through the deep metal via.

(58) **Field of Classification Search**  
CPC ..... H01L 29/402; H01L 29/404  
USPC ..... 257/335, 336, 337, 338, 339, 340, 341,  
257/342, 343

See application file for complete search history.

**17 Claims, 9 Drawing Sheets**



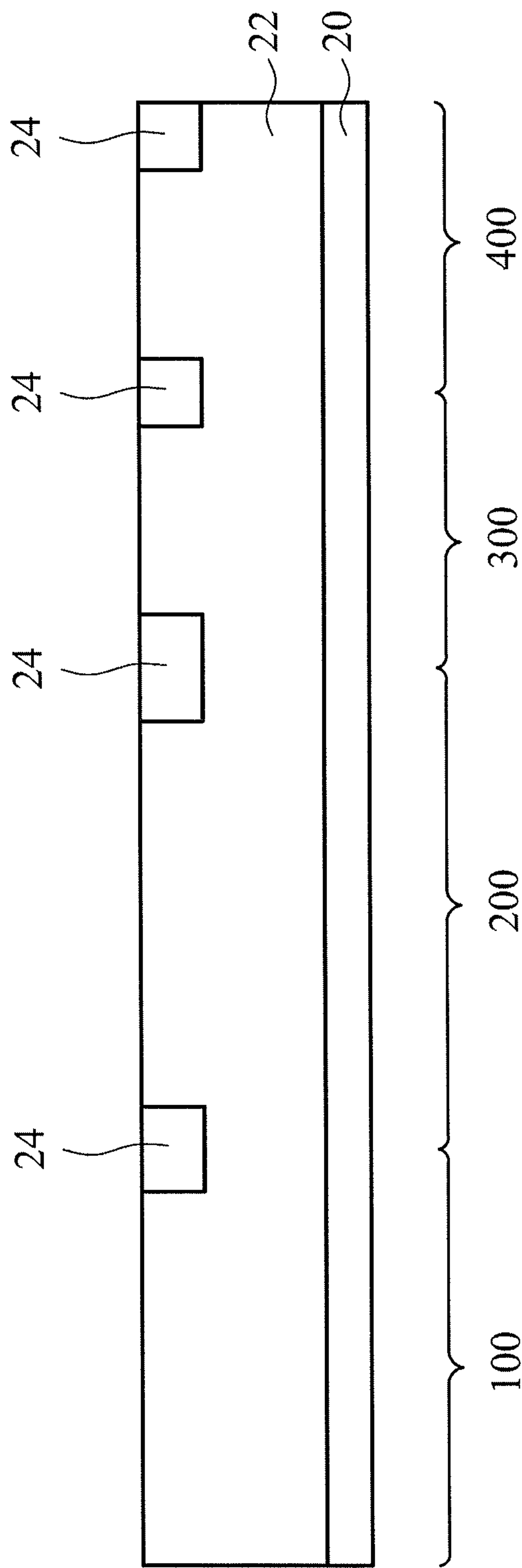


Fig. 1

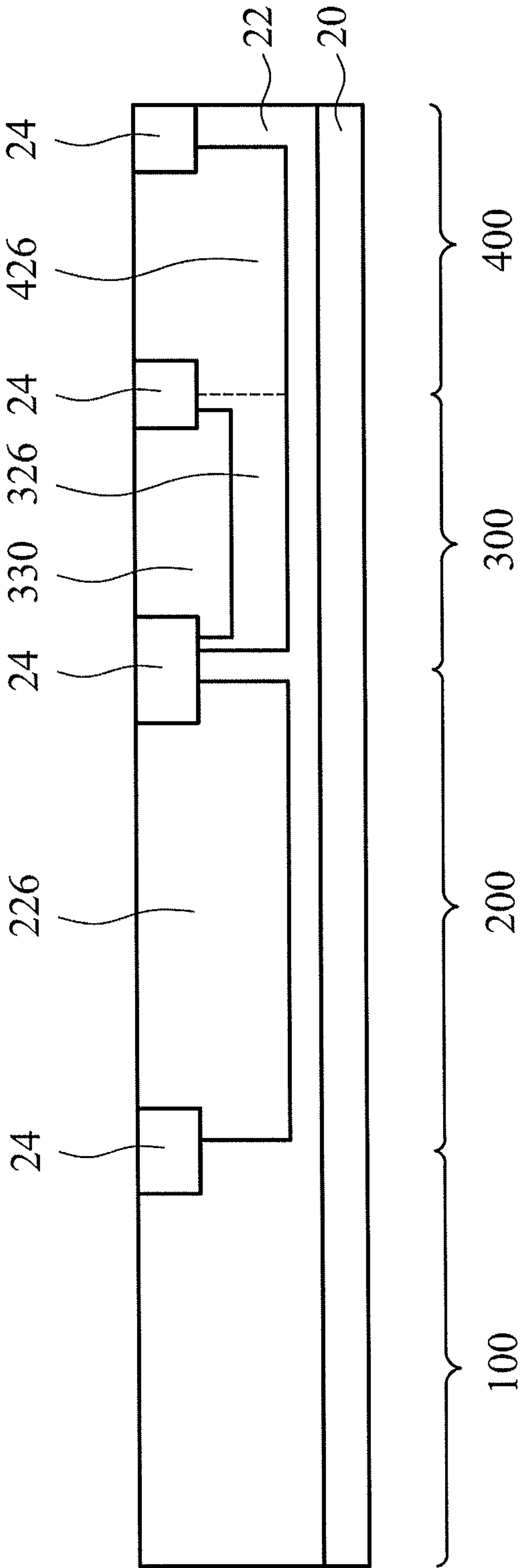


Fig. 2

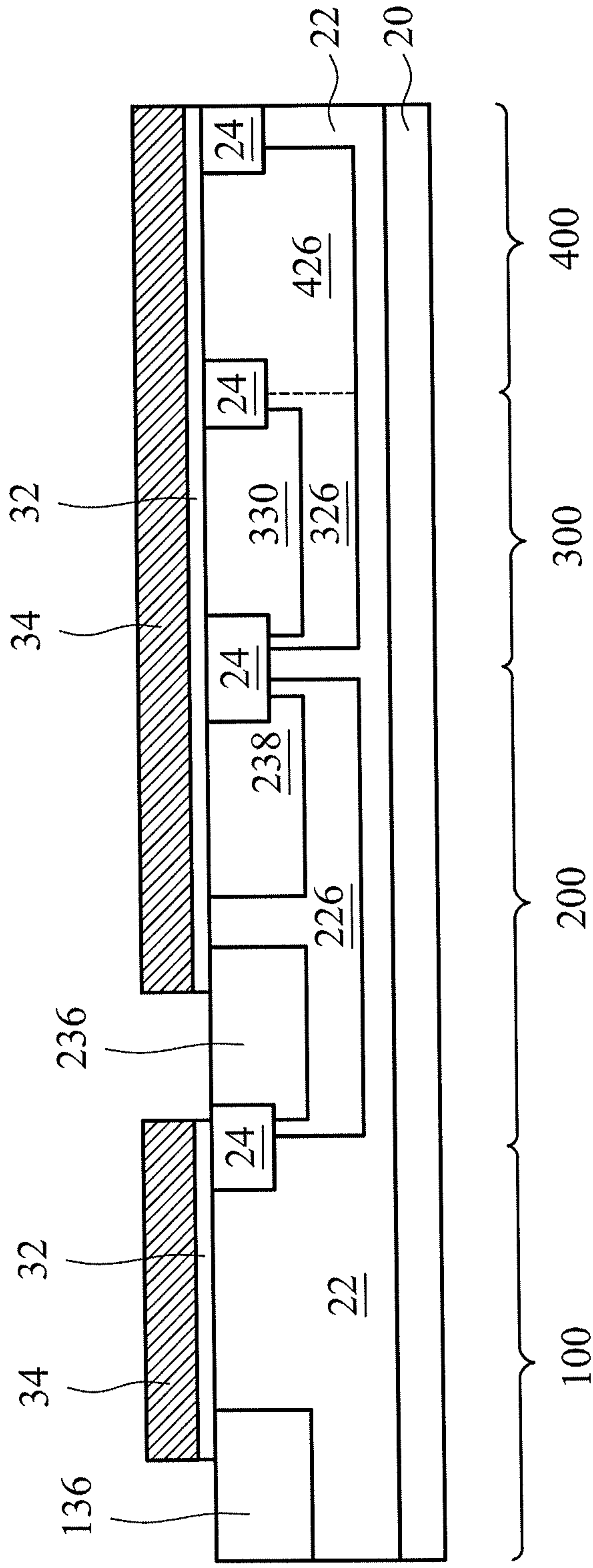


Fig. 3

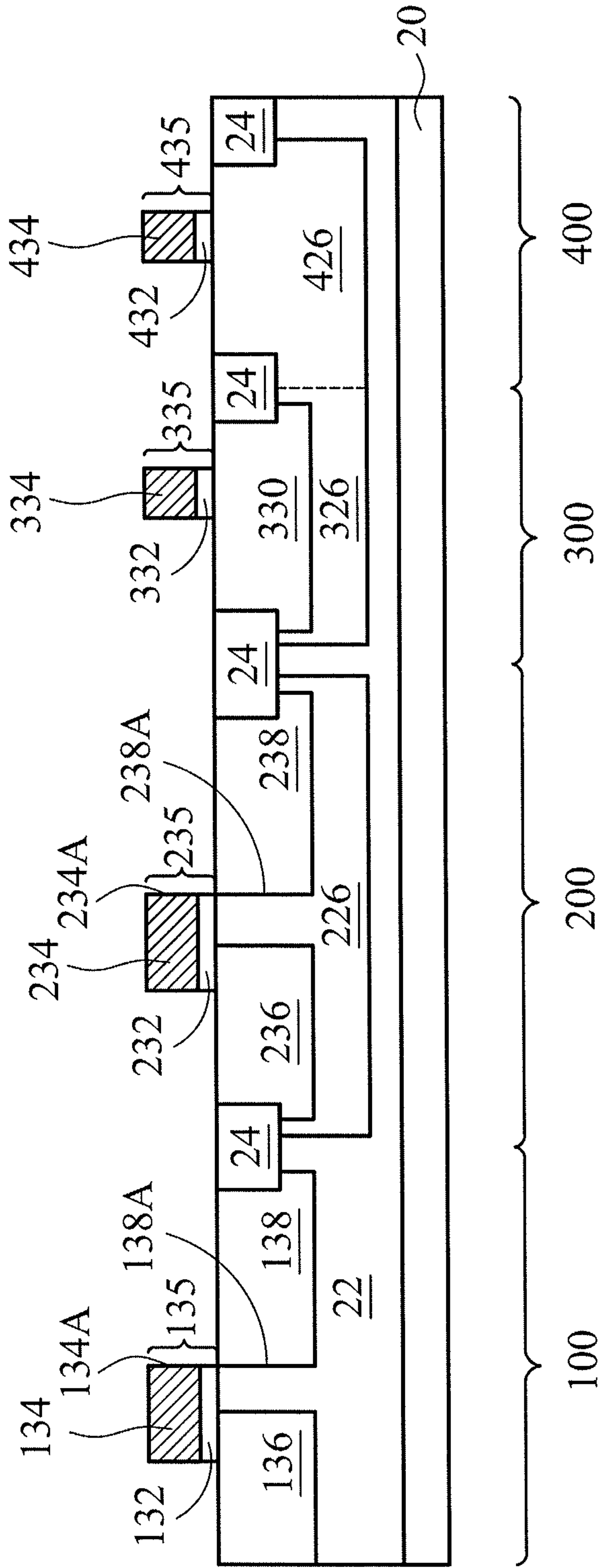


Fig. 4



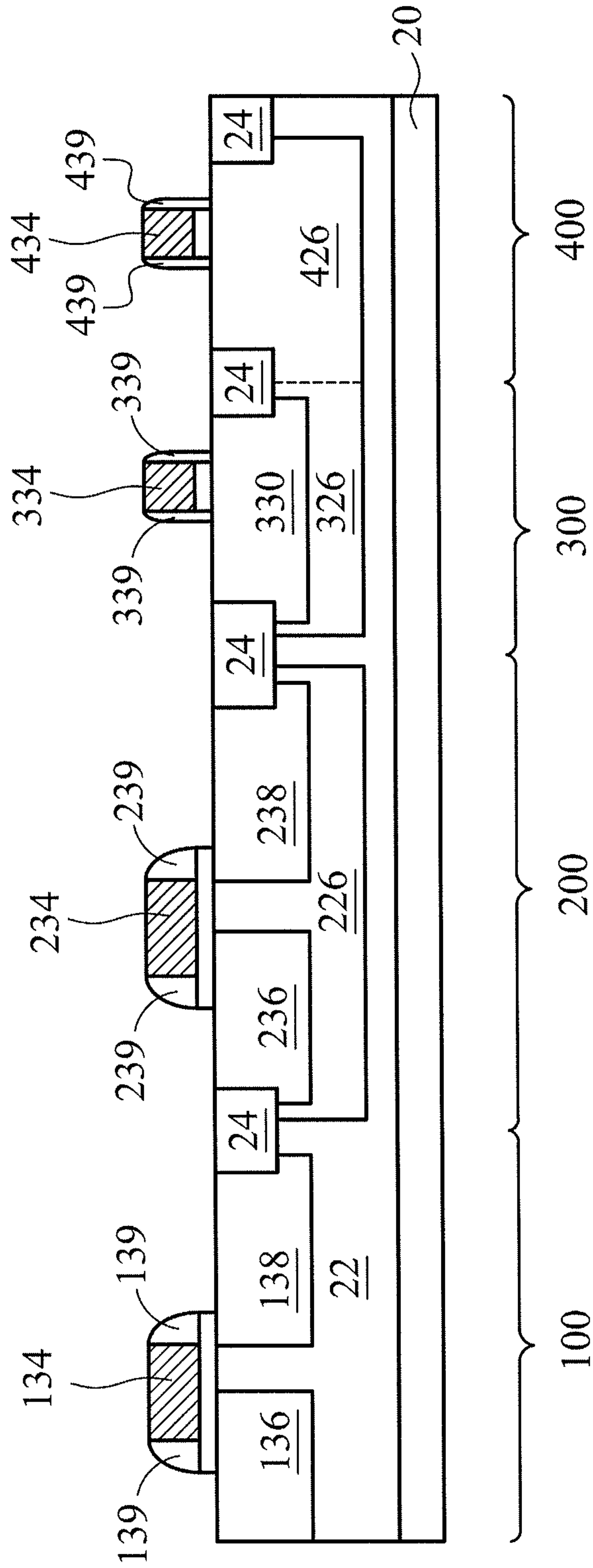


Fig. 5

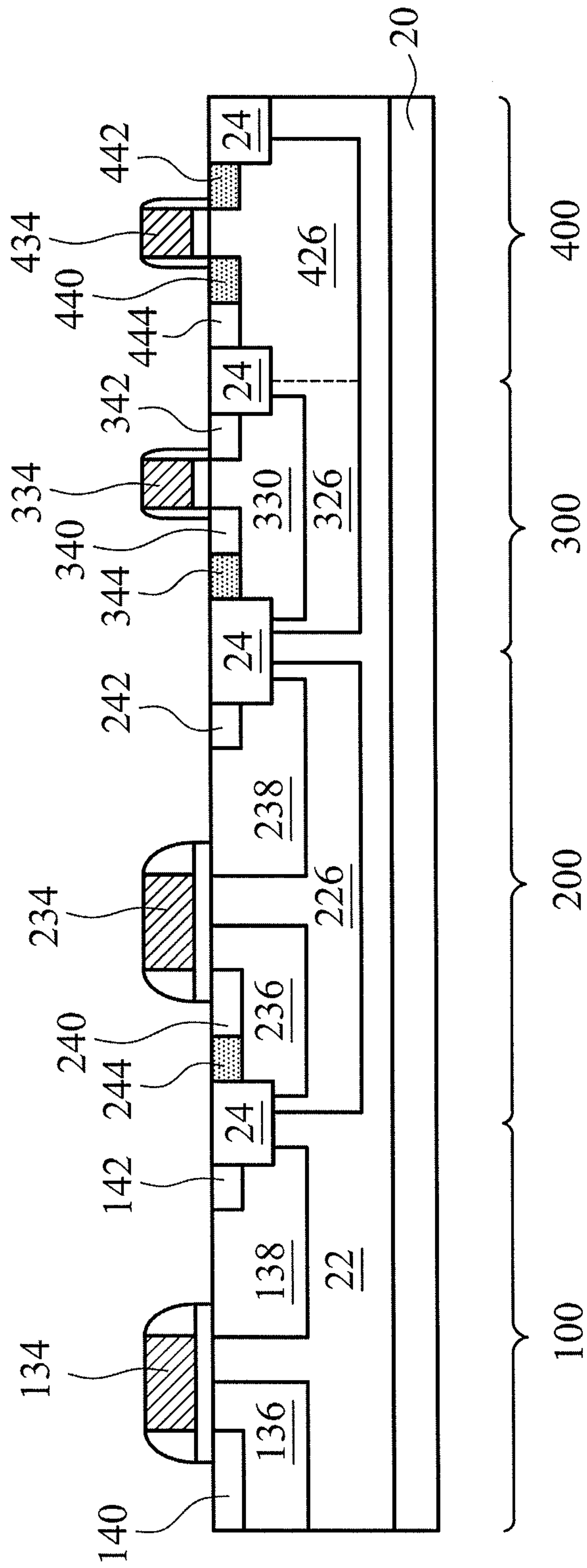


Fig. 6

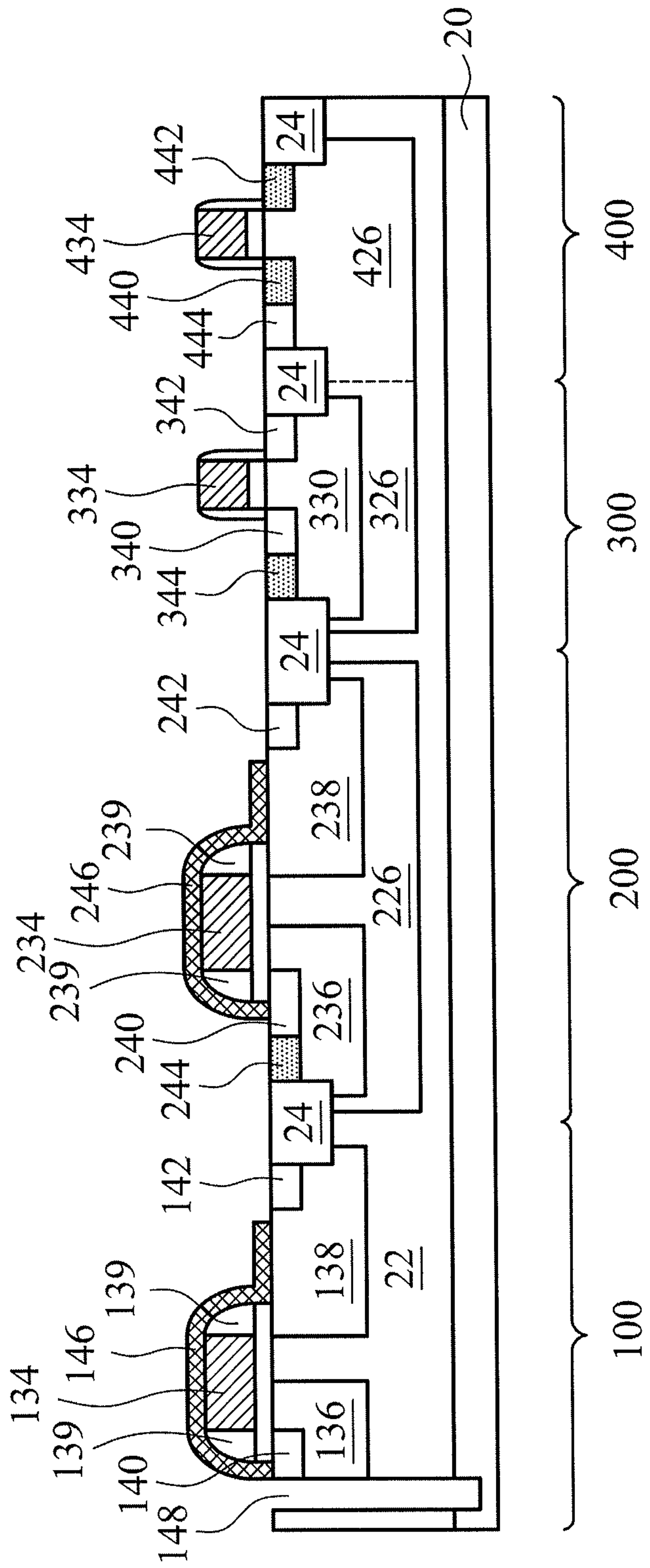


Fig. 7



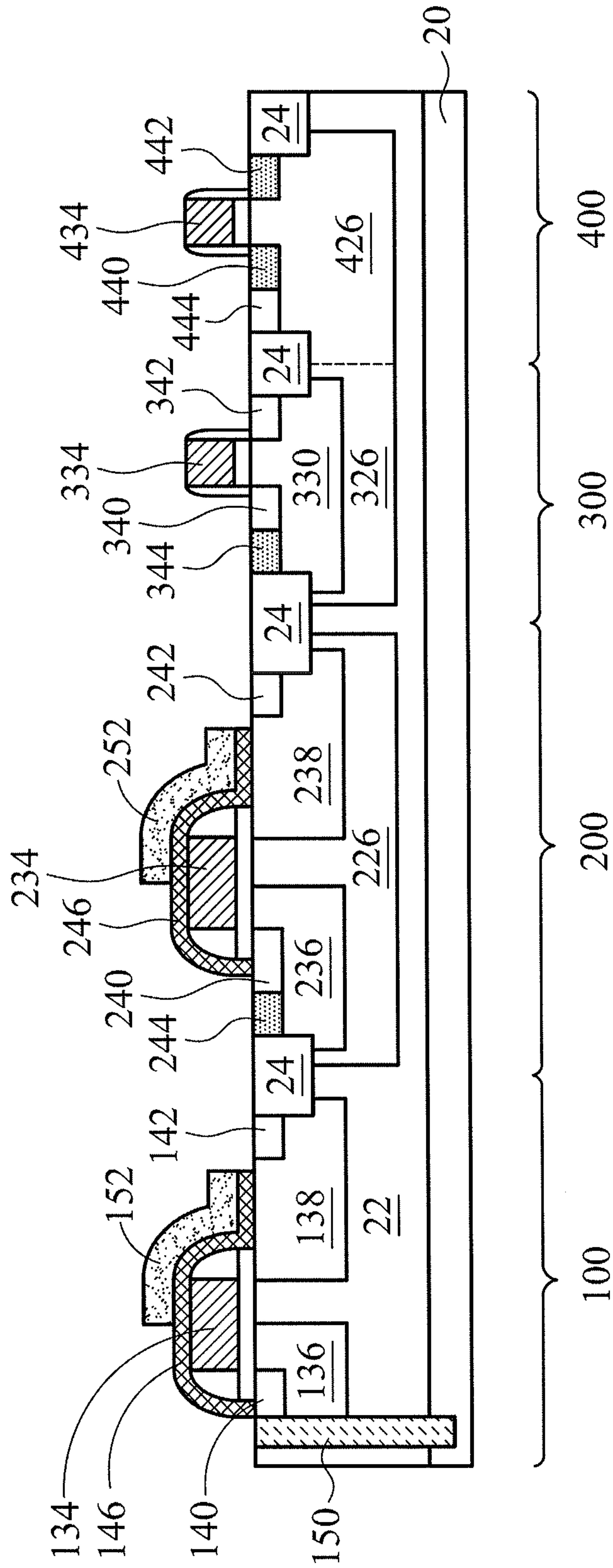


Fig. 8

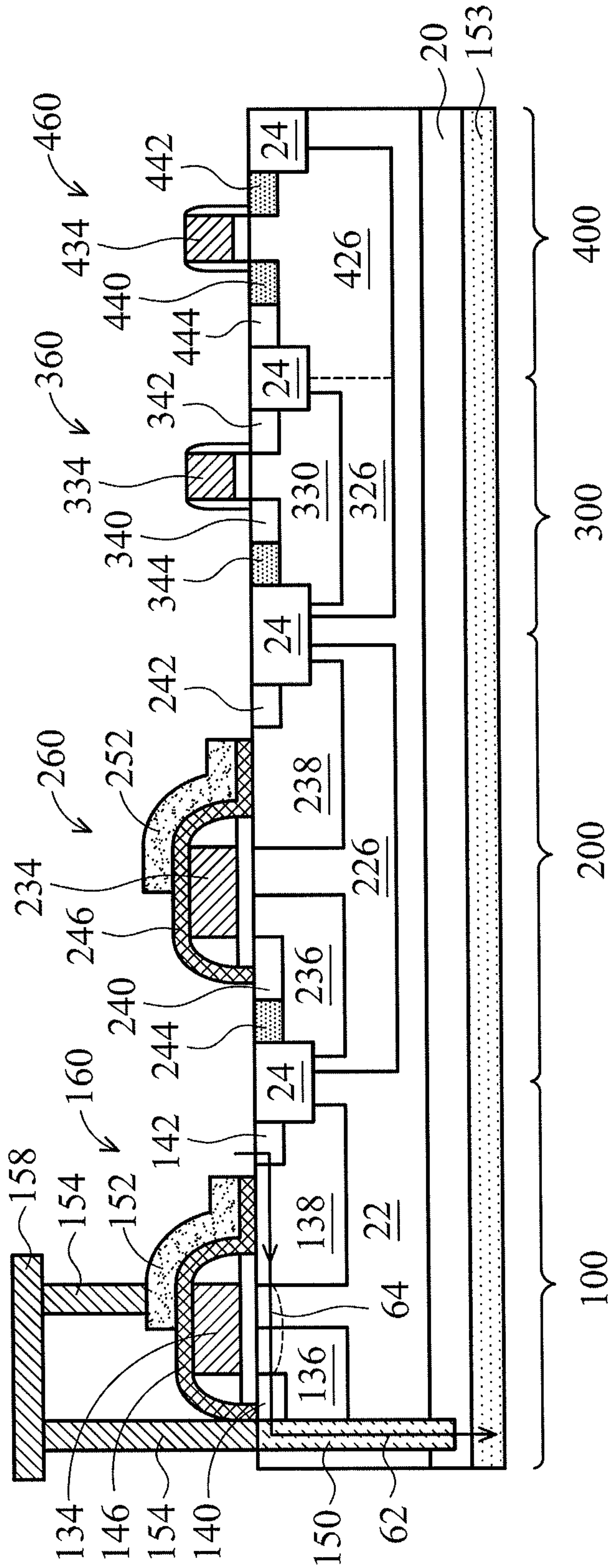


Fig. 9



## VERTICAL POWER MOSFET AND METHODS FOR FORMING THE SAME

### BACKGROUND

In a conventional vertical power Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET), two p-body regions are formed in an n-type epitaxy region. The vertical power MOSFET are such named since its source electrode and drain region are overlapped. A portion of the epitaxy region between the two p-body regions is lightly doped to form an n-type doped region, which is sometimes known as an N-type Junction Field Effect Transistor (n-JFET) region. The p-body regions and the n-JFET region are under a gate dielectric and a gate electrode. When the gate is applied with a positive voltage, the accumulation regions of electrons are formed in the p-body regions. The accumulation regions act as the channel regions that connect the source region of the vertical power MOSFET to the n-JFET region, which is further connected to the drain region of the power MOSFET through the n-type epitaxy region. Accordingly, a source-to-drain current is conducted from the source region to the channels in the p-body regions, the n-JFET region, the epitaxy region, and then to the drain region.

The n-JFET region is underlying the gate electrode, with the gate dielectric layer disposed between the n-JFET region and the gate electrode. There is a large overlap area between the gate electrode and the n-JFET region. As a result, there is a significant gate-to-drain capacitance, which adversely affects the performance, including the speed, of the vertical MOSFET. Furthermore, the n-JFET region is lightly doped since it is a part of the n-type epitaxy region. The resistance of the n-JFET region is thus high, which adversely affects the drive current of the vertical power MOSFET.

### BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the embodiments, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGS. 1 through 9 are cross-sectional views of intermediate stages in the manufacturing of a vertical power Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) in accordance with some exemplary embodiments.

### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the embodiments of the disclosure are discussed in detail below. It should be appreciated, however, that the embodiments provide many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are illustrative, and do not limit the scope of the disclosure.

A vertical power Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) and the method of forming the same are provided in accordance with various exemplary embodiments. The intermediate stages of forming the vertical power MOSFET are illustrated. The variations of the embodiments are discussed. Throughout the various views and illustrative embodiments, like reference numbers are used to designate like elements.

FIGS. 1 through 9 are cross-sectional views of intermediate stages in the formation of an n-type vertical power MOSFET. Referring to FIG. 1, semiconductor layer 20, which may be a semiconductor substrate, is provided. Semiconductor

layer 20 may have a crystalline silicon structure. Alternatively, semiconductor layer 20 is formed of other semiconductor materials such as silicon germanium. In some embodiments, semiconductor layer 20 is a heavily doped layer (P+ layer) doped with a p-type impurity such as phosphorous or arsenic, for example, to an impurity concentration between about  $10^{19}/\text{cm}^3$  and about  $10^{21}/\text{cm}^3$ . In the described embodiments, the term “heavily doped” means an impurity concentration above about  $10^{19}/\text{cm}^3$ . One skilled in the art will recognize, however, that heavily doped is a term of art that depends upon the specific device type, technology generation, minimum feature size, and the like. It is intended, therefore, that the term be interpreted in light of the technology being evaluated and not be limited to the described embodiments.

Over heavily doped semiconductor layer 20, epitaxy layer 22 is formed through epitaxy, and is lightly doped with a p-type impurity. The impurity concentration of epitaxy layer 22 may be between about  $10^{14}/\text{cm}^3$  and about  $10^{16}/\text{cm}^3$ . It is appreciated, however, that the values recited throughout the description are merely examples, and may be changed to different values. Epitaxy layer 22 is hence a P- layer, and is referred to as P- epitaxy layer 22 hereinafter. P- epitaxy layer 22 may be a silicon layer, although other semiconductor materials such as germanium, silicon germanium, III-V compound semiconductors, or the like, may be used to form P- epitaxy layer 22.

Isolation regions 24 are formed adjacent to the top surface of P- epitaxy layer 22. Isolation regions 24 may be Shallow Trench Isolation (STI) regions, and hence are referred to as STI regions 24 hereinafter, although they may also be other types of isolation regions such as field oxides formed through the local oxidation of P- epitaxy layer 22. STI regions 24 may be used to separate different device regions, which include vertical power MOSFET region 100, high-side MOSFET region 200, low-voltage NMOSFET region 300, and low-voltage PMOSFET region 400.

Referring to FIG. 2, High-Voltage N-Well (HVNW) regions 226 is formed in high-side MOSFET region 200, for example, by implanting an n-type impurity into epitaxy layer 22. HVNW regions 326 and 426 are also formed in low-voltage NMOSFET region 300 and low-voltage PMOSFET region 400, respectively. HVNW regions 226, 326, and 426 extend from the top surface of P- epitaxy layer 22 down into P- epitaxy layer 22. The bottom surfaces of HVNW regions 226, 326, and 426 are higher than the top surface of heavily doped semiconductor layer 20. Accordingly, HVNW regions 226, 326, and 426 are spaced apart from heavily doped semiconductor layer 20 by a portion of P- epitaxy layer 22. HVNW regions 226, 326, and 426 may have an impurity concentration between about  $10^{14}/\text{cm}^3$  and about  $10^{17}/\text{cm}^3$ , for example.

Again referring to FIG. 2, p-well region 330 is formed in low-voltage NMOSFET region 300, for example, through an implantation. P-well region 330 extends from the top surface of HVNW region 326 into HVNW region 326. The bottom surface of p-Well region 330 may be higher than the bottom surface of HVNW region 326. Accordingly, p-well region 330 is spaced apart from P- epitaxy layer 22 by a portion of HVNW region 326. P-well region 330 may have an impurity concentration between about  $10^{15}/\text{cm}^3$  and about  $10^{18}/\text{cm}^3$ .

Next, as shown in FIG. 3, gate oxide layer 32 is formed. In some embodiments, the formation process includes a thermal oxidation process. Accordingly, gate oxide layer 32 may comprise silicon oxide. In alternative embodiments, gate oxide layer 32 is formed through deposition. The corresponding gate oxide layer 32 may include silicon oxide, silicon



nitride, silicon oxynitride, silicon carbide, combinations thereof, or multi-layers thereof. Gate electrode layer **34** is formed over gate oxide layer **32**. The formation process may include a blanket deposition of a conductive material. In some embodiments, gate electrode layer **34** comprises polysilicon, although other conductive materials such as metals, metal silicides, or the like, may also be used.

As also illustrated in FIG. 3, some portions of gate electrode layer **34** in vertical power MOSFET region **100** and high-side MOSFET region **200** are removed in a patterning step. An implantation is then performed to form p-body regions **136** and **236** by implanting a p-type impurity in to P-epitaxy layer **22**. The p-type impurity concentration of p-body regions **136** and **236** may be between about  $10^{16}/\text{cm}^3$  and about  $10^{19}/\text{cm}^3$ . In some exemplary embodiments, the implantation of p-body regions **136** and **236** is performed after the patterning of gate electrode layer **34** and before the removal of the portions of gate oxide layer **32** that are underlying the removed portions of gate electrode **34**. After the implantation, the portions of gate oxide layer **32** that are underlying the removed portions of gate electrode **34** are also removed.

Next, referring to FIG. 4, gate oxide layer **32** and gate electrode layer **34** are further patterned to form gate stacks **135**, **235**, **335**, and **435** in device regions **100**, **200**, **300**, and **400**, respectively. An implantation is then performed to form N-type Doped Drain (NDD) regions **138** and **238**, which are in vertical power MOSFET region **100** and high-side MOSFET region **200**, respectively. The implanted n-type impurity may include phosphorous and/or arsenic. The n-type impurity concentration of NDD regions **138** and **238** may be between about  $10^{16}/\text{cm}^3$  and about  $10^{19}/\text{cm}^3$ . The implantation may be substantially vertical, so that edges **138A** and **238A** are aligned to edges **134A** and **234A** of the respectively gate electrodes **134** and **234**. Accordingly, the formation of NDD regions **138** and **238** are self-aligned to the edges **134A** and **234A**. As a result, substantially no overlap exists between gate electrode **134** and NDD region **138**, and substantially no overlap exists between gate electrode **234** and NDD region **238**. This contributes to the reduced gate-to-drain capacitance of the resulting MOSFETs in device regions **100** and **200**.

In FIG. 5, gate spacers **139**, **239**, **339**, and **439** are formed, for example, by depositing a dielectric layer, and etching the dielectric layer to remove the horizontal portions. The remaining vertical portions of the dielectric layer form gate spacers **139**, **239**, **339**, and **439**.

Referring to FIG. 6, an n-type implantation step is performed to form heavily doped n-type source/drain regions **140**, **142**, **240**, **242**, **340**, and **342** and n-type pickup region **444**. The implanted regions may have an n-type impurity concentration between about  $10^{19}/\text{cm}^3$  and about  $10^{21}/\text{cm}^3$ , for example. Furthermore, a p-type implantation step is performed to form heavily doped p-type source/drain regions **440** and **442** and P+ pickup regions **244** and **344**. The implanted regions may have a p-type impurity concentration between about  $10^{19}/\text{cm}^3$  and about  $10^{21}/\text{cm}^3$ , for example.

Referring to FIG. 7, dielectric layers **146** and **246** are formed. Dielectric layer **146** may comprise portions over gate electrode **134**, gate spacers **139**, and/or NDD region **138**. Dielectric layer **146** may further cover N+ region **140** in some embodiments. Dielectric layer **246** may comprise portions over gate electrode **234**, gate spacers **239**, and/or NDD region **238**. Dielectric layers **146** and **246** may comprise an oxide, a nitride, an oxynitride, combinations thereof, and multi-layers thereof. The formation process may include a blanket deposition step to form a blanket layer, followed by a patterning step to pattern the blanket layer. In alternative embodiments,

the patterning of the blanket layer may be performed after the formation of field plates **152** and **252** and deep metal via **150** (not shown in FIG. 7, please refer to FIG. 8).

As also shown in FIG. 7, an etching step is performed to etch N+ source region **140**, p-body region **136**, and P-epitaxy layer **22**. Heavily doped semiconductor layer **20** is exposed to the resulting trench **148**. Trench **148** may also extend into the top portion of heavily doped semiconductor region **20**. The bottom portion of heavily doped semiconductor region **20** is not etched. The sidewalls of N+ region **140** and p-body region **136** may be exposed to trench **148** in some embodiments.

In FIG. 8, a conductive material is filled into trench **148** and over dielectric layers **146** and **246**. The formation process may include a blanket deposition step, and a patterning/etching-back step to remove excess portions of the conductive material. The portions of the conductive material over dielectric layers **146** and **246** form field plates **152** and **252**, respectively. Field plate **152** may, or may not, include a first portion overlapping a portion of gate electrode **134**, and may include a second portion level with and on the drain side of gate electrode **134**. The second portion of field plate **152** overlaps NDD region **138**. Similarly, field plate **252** may, or may not, include a first portion overlapping a portion of gate electrode **234**, and may further include a second portion level with and on the drain side of gate electrode **234**. The conductive material for forming field plates **152** and **252** may comprise a metal such as tungsten, aluminum, nickel, or the like, although other conductive materials such as polysilicon, metal silicides, and the like, may also be used. The portion of the conductive material forms deep via **150**, which is electrically coupled to, and contacts, N+ region **140** and p-body region **136**. Deep via **150** is also electrically shorted to heavily doped semiconductor layer **20**.

Referring to FIG. 9, an electrical connection is formed to electrically short deep metal via **150** to field plate **152**. The electrical connection may include contact plugs **154** and metal line **158**, for example. Furthermore, a conductive material is deposited on heavily doped semiconductor region **20** to form source electrode **153**. Source/drain regions **140/142** and source electrode **153** are thus formed on the opposite sides of the respective wafer and chip. In some embodiments, source electrode **153** comprises a metal such as aluminum, copper, tungsten, nickel, and/or the like. With the formation of deep via **150**, field plate **152** is shorted to source electrode **153** (through heavily doped semiconductor layer **20**). Also, the source region **140** is connected to the source electrode **153** through deep via **150**. Vertical power MOSFET **160** is thus formed. The formation of high-side MOSFET **260**, low-voltage NMOSFET **360**, and low-voltage PMOSFET **460** is also finished.

An on-current of vertical power MOSFET **100** is schematically illustrated using curved arrow **62**, which passes through drain region **142**, NDD region **138**, channel region **64** in P-epitaxy layer **22** and p-type body **136**, source region **140**, deep via **150**, heavily doped semiconductor layer **20**, and reaches source electrode **153**.

Although the embodiments shown in FIGS. 1 through 9 provide methods of forming n-type vertical power MOSFETs, one skilled in the art will realize that the provided teaching is readily available for the formation of p-type vertical power MOSFETs, with the conductivity types of the respective doped semiconductor regions inverted.

In the embodiments, NDD region **138** is self-aligned to the edge of gate electrode **134**. Therefore, the overlap between gate electrode **134** and NDD region **138** is minimized, and hence the gate-to-drain capacitance is minimized. Field plate **152** is shorted to semiconductor source region **140** and source



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electrode **153**, and hence field plate **152** does not contribute to the gate-to-drain capacitance. Source electrode **153** and source/drain regions **140/142** are on opposite sides of the respective chip, and source electrode **153** is underlying source/drain regions **140/142**. Since channel **64** is horizontal, the breakdown voltage of the respective MOSFET **160** is determined by the lateral sizes, such as the width of NDD region **138** and the width of p-body region **136**, and the width of the portion of P- epitaxy layer **22** between p-body region **136** and NDD region **138**. Deep via **150**, which may be a metal via, is connected to the heavily doped semiconductor layer **20**. Deep via **150** forms the deep body pickup region for reducing the bulk resistance of vertical power MOSFET **160**.

In accordance with embodiments, a device includes a semiconductor region in a semiconductor chip, a gate dielectric layer over the semiconductor region, and a gate electrode over the gate dielectric. A drain region is disposed at a top surface of the semiconductor region and adjacent to the gate electrode. A gate spacer is on a sidewall of the gate electrode. A dielectric layer is disposed over the gate electrode and the gate spacer. A conductive field plate is over the dielectric layer, wherein the conductive field plate has a portion on a drain side of the gate electrode. A deep metal via is disposed in the semiconductor region. A source electrode is underlying the semiconductor region, wherein the source electrode is electrically shorted to the conductive field plate through the deep metal via.

In accordance with other embodiments, a device includes a metal source electrode, a heavily doped semiconductor layer of a first conductivity type over the metal source electrode, and a lightly doped semiconductor layer of the first conductivity type over the heavily doped semiconductor layer. A gate dielectric is over the lightly doped semiconductor layer. A gate electrode is over the gate dielectric. A drain region and a source region are on opposite sides of the gate electrode, wherein the drain region and the source region are of a second conductivity type opposite the first conductivity type. A deep metal via extends from a top surface of the source region down to contact the heavily doped semiconductor layer, wherein the deep metal via is electrically shorted to the source region.

In accordance with yet other embodiments, a method includes performing an epitaxy to form a lightly doped semiconductor layer of a first conductivity type over a heavily doped semiconductor substrate of the first conductivity type, forming a gate dielectric over the lightly doped semiconductor layer, and forming a gate electrode over the gate dielectric. A drain region and a source region are formed on opposite side of the gate electrode, wherein the drain region and the source region are of a second conductivity type opposite the first conductivity type. A trench is formed to extend from a top surface of the source region downwardly to contact the heavily doped semiconductor substrate. The trench is filled with a metallic material to form a deep metal via. A source electrode is deposited underlying the heavily doped semiconductor substrate, wherein the deep metal via is shorted to the source region and the source electrode.

Although the embodiments and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the embodiments as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to the particular embodiments of the process, machine, manufacture, and composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the disclosure, processes,

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machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein may be utilized according to the disclosure. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps. In addition, each claim constitutes a separate embodiment, and the combination of various claims and embodiments are within the scope of the disclosure.

What is claimed is:

**1.** A device comprising:

- a semiconductor region in a semiconductor chip;
- a gate dielectric layer over the semiconductor region;
- a gate electrode over the gate dielectric;
- a drain region at a top surface of the semiconductor region and adjacent to the gate electrode;
- a gate spacer on a sidewall of the gate electrode, wherein the gate spacer is on a drain side of the gate electrode;
- a dielectric layer over the gate electrode and the gate spacer;
- a conductive field plate over the dielectric layer, wherein the conductive field plate comprises a first portion on the drain side of the gate electrode, with the first portion extending farther away from the gate electrode than the gate spacer, and a second portion extending further away from the semiconductor region than the gate electrode;
- a deep metal via in the semiconductor region; and
- a source electrode underlying the semiconductor region, wherein the source electrode is electrically shorted to the conductive field plate through the deep metal via.

**2.** The device of claim **1** further comprising a Doped Drain (DD) region in the semiconductor region, wherein the DD region has an impurity concentration lower than an impurity concentration of the drain region, and wherein the DD region is laterally between the gate electrode and the drain region, and has a bottom lower than a bottom of the drain region.

**3.** The device of claim **2**, wherein an edge of the DD region is substantially aligned to an edge of the gate electrode.

**4.** The device of claim **1** further comprising:

- a semiconductor source region, wherein the semiconductor source region and the drain region are on opposite sides of the gate electrode, and are of a same conductivity type; and
- a body region extending under the gate dielectric layer, with the semiconductor source region in the body region, wherein the deep metal via contacts sidewalls of the semiconductor source region and the body region.

**5.** The device of claim **1**, wherein the semiconductor region comprises:

- a heavily doped layer; and
- a lightly doped layer over the heavily doped layer, wherein the lightly doped layer and the heavily doped layer are of an opposite conductive type than a conductivity type of the drain region, and wherein the deep metal via penetrates through the lightly doped layer, and is in contact with the heavily doped layer.

**6.** The device of claim **1** further comprising an additional MOS device selected from the group consisting essentially of a low-voltage MOSFET and a high-side MOSFET formed at a top surface of the semiconductor region.

**7.** The device of claim **6**, wherein the source electrode extends underlying the additional MOS device.



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**8.** A device comprising:  
 a metal source electrode;  
 a heavily doped semiconductor layer of a first conductivity type over the metal source electrode;  
 a lightly doped semiconductor layer of the first conductivity type over the heavily doped semiconductor layer;  
 a gate dielectric over the lightly doped semiconductor layer;  
 a gate electrode over the gate dielectric;  
 a drain region and a source region on opposite sides of the gate electrode, wherein the drain region and the source region are of a second conductivity type opposite the first conductivity type;  
 a dielectric layer comprising a first portion over a top surface of the gate electrode, and a second portion extending on a drain side of the gate electrode;  
 a conductive field plate over the dielectric layer, wherein the conductive field plate comprises a first portion on the drain side of the gate electrode, with the first portion level with the gate electrode, and a second portion extending further away from the lightly doped semiconductor layer than the gate electrode; and  
 a deep metal via extending from a top surface of the source region down to contact the heavily doped semiconductor layer, wherein the deep metal via is electrically shorted to the metal source electrode, and wherein an edge of the deep metal via is in physical contact with an edge of the source region.

**9.** The device of claim **8** further comprising a body region of the first conductivity type extending underlying the gate dielectric, wherein the source region is in the body region, and wherein the deep metal via is in contact with sidewalls of the source region and the body region.

**10.** The device of claim **8** further comprising a Doped Drain (DD) region having an edge substantially aligned to an edge of the gate electrode, wherein the drain region is in the DD region, and wherein a portion of the DD region laterally spaces the drain region apart from the gate electrode.

**11.** The device of claim **8**, wherein the conductive field plate and the deep metal via are formed of a same material.

**12.** The device of claim **8** further comprising:  
 a high-voltage well region of the second conductivity type in a top portion of the lightly doped semiconductor layer; and

a low-voltage MOS device comprising a source region and a drain region, with an edge of the source region and an edge of the drain region substantially aligned to respective edges of a gate electrode of the low-voltage MOS device, wherein the source region and the drain region of the low-voltage MOS device are in the high-voltage well region.

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**13.** The device of claim **8** further comprising:  
 a high-voltage well region of the second conductivity type in a top portion of the lightly doped semiconductor layer; and  
 a high-side MOS device comprising a source region and a drain region, wherein the source region and the drain region of the high-side MOS device are in the high-voltage well region.

**14.** A device comprising:  
 a metal source electrode;  
 a heavily doped semiconductor layer of a first conductivity type over the metal source electrode;  
 a lightly doped semiconductor layer of the first conductivity type over the heavily doped semiconductor layer;  
 a gate dielectric over the lightly doped semiconductor layer;  
 a gate electrode over the gate dielectric;  
 a drain region and a source region on opposite sides of the gate electrode, wherein the drain region and the source region are of a second conductivity type opposite the first conductivity type, wherein the gate dielectric, the gate electrode, the source region, and the drain region form a vertical power Metal Oxide Semiconductor Field Effect Transistor (MOSFET);  
 a body region of the first conductivity type, wherein a portion of the body region is overlapped by the gate electrode, and wherein the source region is in the body region;  
 a deep metal via extending from a top surface of the source region down to contact the heavily doped semiconductor layer, with the deep metal via in physical contact with sidewalls of the source region and the body region, wherein an on-current of the MOSFET is configured to flow between the metal source electrode and the drain region, and wherein the on-current is configured to flow through the deep metal via; and  
 a conductive field plate comprising a first portion overlapping the gate electrode, and a second portion level with the gate electrode, with the second portion on a drain side of the gate electrode.

**15.** The device of claim **14** further comprising a Doped Drain (DD) region having an edge substantially aligned to an edge of the gate electrode, wherein the drain region is in the DD region, and wherein a portion of the DD region laterally spaces the drain region apart from the gate electrode.

**16.** The device of claim **15** further comprising:  
 a dielectric layer comprising a first portion over a top surface of the gate electrode, and a second portion overlapping the DD region, wherein the conductive field plate is over the dielectric layer.

**17.** The device of claim **14**, wherein the conductive field plate and the deep metal via are formed of a same material.

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